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16. ABSTRACT

The purpose of this project was to search for and identify any trends in water chemistry and fish communities in Pennsylvania waters which would indicate that acid precipitation was affecting them adversely. No new data collection was to be included.

Five existing data bases, including original data collected by the authors, were examined for the existence of water analyses from the same or nearby locations separated by at least one year. (Analyses involving known or suspected influence of acid mine drainage were omitted.) Of a total of 983 analysis reports which were usable, there were 314 cases with two or more such points. Of these 107 or 34% showed a decrease in pH, alkalinity, or both. Average decrease in pH was 0.4 units with a maximum case of 1.3 units. Average decrease in alkalinity was 15.1 mg/l (as $CaCO_3$) with a maximum case of 105 mg/l. The average time span between earliest and latest sample was 8.5 years.

When the data were separated by physiographic provinces, it became apparent that although the majority of the decreases occurred in streams on the relatively insoluble rocks of the Allegheny Plateau, there were also many cases in the ridge-and-valley province and other regions. Many of these decreases are to pH levels considered marginal for growth and reproduction of trout and other fishes.

Seventy-one of the 107 analyses showing decreased pH or alkalinity included fish collection data. In 40 of these cases (58%), the number of fish species present decreased as well.

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DISCLAIMER

One of the principal reasons for the preparation of this report for the Environmental Protection Agency was to supply scientifically valid information which could be incorporated into the EPA SO_2-Particulate Matter criteria document, presently in the final stages of preparation. A strict requirement pertaining to that document is that any scientific information used there must be published (or at least in press) by January 1, 1980. Because of this demanding time constraint, it was necessary that the contractor prepare this report in a shorter time than would ordinarily be attempted, and that it be published by EPA without undergoing peer review. We feel that early publication of these results in order to stimulate the broadest scientific discussion prior to completion of the criteria document justified waiving our normally more rigorous prepublication review requirements. Publication, however, does not signify that the contents necessarily reflect the views and policies of EPA, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

Effective regulatory and enforcement actions by the Environmental Protection Agency would be virtually impossible without sound scientific data on pollutants and their impact on environmental stability and human health. Responsibility for building this data base has been assigned to EPA's Office of Research and Development and its 15 major field installations, one of which is the Corvallis Environmental Research Laboratory.

The primary mission of the Corvallis Laboratory is research on the effects of environmental pollutants on terrestrial, freshwater, and marine ecosystems; the behavior, effects and control of pollutants in lakes and streams and the development of predictive models on the movement of pollutants in the biosphere.

This report has assembled evidence for increased acidity of a number of Pennsylvania streams, decreases of fish populations in many, and points to acid precipitation as a likely cause.

Thomas A. Murphy, Director
Corvallis Environmental Research Laboratory

ABSTRACT

The purpose of this project was to search for and identify any trends in water chemistry and fish communities in Pennsylvania waters which would indicate that acid precipitation was affecting them adversely. No new data collection was to be included.

Five existing data bases, including original data collected by the authors, were examined for the existence of water analyses from the same or nearby locations separated by at least one year. (Analyses involving known or suspected influence of acid mine drainage were omitted.) Of 983 analysis reports which were usable, there were 314 cases with two or more such points. Of these 107 or 34% showed a decrease in pH, alkalinity, or both. Average decrease in pH was 0.4 units with a maximum case of 1.3 units. Average decrease in alkalinity was 15.1 mg/l (as $CaCO_3$) with a maximum case of 105 mg/l. The average time span between earliest and latest sample was 8.5 years.

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Seventy-one of the 107 analyses showing decreased pH or alkalinity included fish collection data. In 40 of these cases (58%), the number of fish species present decreased as well.

This report was submitted in fulfillment of Contract Number B0835NAEX under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from May to October, 1979, and work was completed as of October 1, 1979.

CONTENTS

Foreword. iii
Abstract. iv
Figures vi
Tables. vi
Acknowledgements. vii

1. Introduction. 1
2. Conclusions 4
3. Recommendations 4
4. Materials and Methods 5
5. Results and Discussion. 8

References. 19

FIGURES

Number

1. Card form used for recording and analysis of available data 7

2. County map of Pennsylvania showing approximate boundaries of physiographic provinces and locations of waters showing decrease in pH or alkalinity or both. 12

3. Stream map of Pennsylvania showing major drainage basins and locations of waters showing decrease in pH or alkalinity or both. . . 15

TABLES

1. Summary of decreases in pH, alkalinity, and number of fish species found for Pennsylvania as a whole 8

2. pH, alkalinity, and number of fish species for Pennsylvania waters showing decreases as described in test. 9

3. Water chemistry and fish population records summarized by physiographic province. 14

4. Water chemistry and fish population records summarized by major watershed . . . . . .

5. Selected waters showing serious symptoms of acidification 17

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INTRODUCTION

In just a few years, the problem of acid precipitation has grown from a suspicion held by a few scientists to a matter of international concern characterized by large conferences, a large amount of new research effort (only part of which is receiving adequate financial support), and large numbers of review articles in both the popular and scientific press (most recently, see Likens et al., 1979). No one is sure of either its extent or its time of beginning. Indeed, it undoubtedly has been developing since the dawn of the industrial age.

The increasing acidity in precipitation has been linked to anthropogenic sources, i.e. coal combustion, petroleum combustion, and nonferrous metal production (Kellogg et al., 1972). The major cause of the acidification has been the addition of SO_2 (sulfur dioxide) from the combustion of fossil fuels and the subsequent production of the strong acid H_2SO_4 (sulfuric acid). This transformation may take several pathways (Kellogg et al., 1972; Brosset, 1973). A second strong acid, HNO_3 (nitric acid), has also been forming at increasing rates in the atmosphere. The formation of this acid also stems from fossil fuel combustion, especially automobile exhausts. Thus the highest concentrations of HNO_3 are evident around metropolitan areas. Both of these strong acids are now present in such high concentration that the natural buffering capacity of the atmosphere is no longer able to neutralize their effects. The pH of pure rainwater saturated with carbon dioxide should be 5.7, but the addition of strong acids to the atmosphere is driving it down well below this level (Johnson, Reynolds, and Likens, 1972).

Only recently have the effects of increasing acidity been appearing in the aquatic ecosystem. The problem facing us now is that (due to safety and other problems with the use of nuclear power and our difficulties in implementing either conservation or alternative energy sources), the use of fossil fuels is increasing, thus compounding the acid precipitation effect. Man contributes about one-half as much sulfur to the atmosphere as does nature now, and it has been predicted that by the year 2000 the amount will be equal (Kellogg et al., 1972). Estimates are that by the year 1995, 350 new coal-fired plants will be built and that sulfur emissions will increase by 2 million tons, corresponding to a threefold increase in coal usage (Carter, 1979).

Increased acidity has been reported primarily in the northern hemisphere. The river systems on the west coast of Sweden have decreased 1.8 units in pH since the 1930s (Schofield, 1976). In 18 Norwegian lakes there has been a doubling of sulfate since the 1950s (Almer et al., 1974). Similar increases in acidity have been found in parts of Scandinavia and in numerous lakes west of Sudbury, Ontario, with increases of 200- and 100-fold respectively (Beamish and Harvey, 1972; Likens and Bormann, 1974). In the northeastern United States, the increase in acidity began to be noticed about twenty years ago and

now the pH of the precipitation ranges between 2.1 and 5 (Likens and Bormann, 1974; Newman, 1975).

After analysis of the literature it becomes apparent that the main thrust of acid precipitation research has been directed at lake ecosystems, not at streams. This may be because, due to low turnover rates, the effects of acidification should be more obvious in lakes than in streams. However, we feel that the effects on streams may prove to be equally as serious as those on lakes, especially in the susceptible areas of the Appalachians. For a thorough review of the literature covering studies prior to 1976, consult Wright (1976).

The Pennsylvania Cooperative Fishery Research Unit has been studying factors influencing production of native trout in infertile streams of the Allegheny Plateau for over 5 years. One of the common features of these streams is their low pH and alkalinity. These are usually between 4.5-5.5 and 0-10 mg/l (as $CaCO_3$) respectively. Although it is recognized that nearly any source of hydrogen ions will upset the pH of such pure-water streams, acid precipitation and/or acid from headwater bogs seem the most likely causes of the low pH. Samples taken early in our studies indicated that (a) the pH is equally low above and below the headwater bog areas; (b) the water emerging from springs on the hillsides has a pH as low as that in the streams; and (c) the pH of rainfall in the area is consistently near 3.8, lower than the streams (and, in fact, lower than the rainfall values for this area indicated in various published reviews such as Likens et al. (1979), which does not even include the Allegheny Plateau region of Pennsylvania and West Virginia among those areas "sensitive" to acid precipitation). These factors all seem to lend support to the assumption that acid precipitation is the primary factor in the acidification of Pennsylvania's unpolluted streams.

The factors involved in our area seem to be similar to those evaluated by Seip and Tollan (1978) in concluding that acid precipitation must be the prime cause of the well-known acidification of rivers and lakes in southern Norway. The majority of the sensitive streams identified in the present study are located on forested land, usually in public ownership, and are subject to few significant human influences. Although there may be occasional exceptions, we believe that acid precipitation is the most probable cause of acidification in the streams we have identified; and that there are many more streams in the state, equally affected, which we were unable to identify simply because of missing or inadequate data.

The most immediate danger from stream and lake acidification is, of course, to fish populations and to their food. Although most of the published reports on this topic involve fish populations in lakes, we believe that similar cause-effect relationships are likely for stream fish.

Complete losses of fish populations have been reported in several areas of Europe (Almer et al., 1974), and in Ontario (Beamish and Harvey, 1972), among other places. In most cases these losses were preceded by symptoms such as poor recruitment, failure of females to reach spawning condition, heavy mortality of eggs and/or larvae, deformed fins, shortening of gill covers, and rising concentrations of toxic elements such as aluminum and mercury. In

Pennsylvania waters, we suspect that the harmful effects to fish populations will occur through such immediate symptoms (i.e., through reduced growth and reproduction) and/or through interference with the food supply, rather than from direct toxicity of acidic water.

Two earlier investigators from our group completed limited studies on the production of periphyton algae and of insect larvae in poorly-buffered, acidic streams. Bender (1978) reported that pH affects species composition of periphyton algae but not species number or diversity, and that total biomass and productivity were not limited. Certain species become dominant only in acidic streams. Hale (1978) showed that in an acidic stream, detritus-feeding insects were dominant, while in a similar stream of neutral pH, herbivorous species dominated. The significance of these findings to fish production is not known. We are also currently investigating the significance of mineral nutrition of fish as related to these acidified streams.

CONCLUSIONS

Although the data upon which this report is based are not sufficiently strong to define statistically valid relationships, it seems clear that there is a definite overall trend toward increasing acidity in many Pennsylvania streams, with the loss of components of the fish populations in many. Field experiments with static limestone beds are being carried out on a number of streams in which the pH is at or near lethality for trout. Precipitation chemistry data are lacking, but elimination of streams possibly affected by acid mine drainage suggests acid precipitation as a likely cause of the observed changes.

RECOMMENDATIONS

A program of investigation should be undertaken to supplement the data utilized in this report with the information needed to document the current conditions and trends indicated for Pennsylvania streams, and their causes.

A list is presented illustrating probable worst conditions existing at present in Pennsylvania surface waters not affected by acid mind drainage. These waters should be monitored for changes in biological or chemical systems related to increasing acidity.

MATERIALS AND METHODS

This study was funded in early May 1979 with a completion date for this report of September 30. With less than 5 months available for the work, it was necessary to limit the study to existing data in locations known to us. Much as we would like to have made field checks of many of the streams reported (and plan to in the near future), the available time did not permit it.

Five data banks were identified and used in the study, as follows:

1. Data collected and compiled by the Pennsylvania Cooperative Fishery Research Unit in connection with various studies of trout production in infertile streams over the past five years. These data exist in punch-card form but in a non-standard local format.

2. Collection station files of The Pennsylvania State University Fish Collection. These include over 1000 locations throughout the state and have been organized by Dr. Edwin L. Cooper, curator. Most of the collections which have water quality data were made during the 1960s (for description see Cooper and Wagner, 1973). Although part of the data is available on compter tape, it is in a non-standard local format and not in a convenient form for machine retrieval of the data needed for the present study.

3. Stream survey files of the Pennsylvania Fish Commission. These are mostly in raw format on data sheets or in report letters. They include data from the 1940s to the present. A statewide fishery survey which will take several years to complete is now in progress and much of the data generated has been entered into a computer file. The access program for this file is not yet operational, and the file does not include information from earlier surveys.

4. Stream surveys and spot measurements by the Pennsylvania Department of Environmental Resources and its predecessor agencies. These are primarily from the 1970s and were usually made in response to reports of pollution problems. However, they complement the Fish Commission data by being mainly from the lower, more developed parts of watersheds, while the Fish Commission surveys are primarily of the upper, less developed sections. These files are all in letter or field data sheet form.

5. Stream monitoring data of the Pennsylvania Department of Environmental Resources. These data are generated routinely by periodic sampling of specific stations throughout the state, and cover the last several years. It is in the standard STORET computer format, but was of limited use to us because the printout we obtained gave the data in terms of averages, masking trends of the time span in which we were interested. It is possible that more intense manipulation of the field would yield data

usable for detecting trends in pH and alkalinity, but shortage of time and money prevented our attempting this.

Because of the widely-varying formats used in these data bases, and the necessity to do time-consuming major programming jobs to use them with computer techniques, we decided to forego the advantages of machine data manipulation for the advantages of manual methods. A standard 4 x 6-inch card was developed (Figure 1) for recording the pertinent data for several samples from a given location. As we proceeded with examination of each data bank (in the order given above), each sample location was evaluated to determine whether it justified starting a new card or if it was sufficiently close (generally within one mile with no major tributaries or other influences between) to an already-recorded station to be listed on the same card. The major time consumption of the study was connected with the laborious task of identifying and matching these station locations, many of which were labeled with place names not on the USGS topographic maps or other references available. (Note: we urge other workers to record and report their collection station data with standard coordinates using place names found on the USGS maps!) If such geographic matching could not be done the sample was eliminated from further consideration; this also was done if the sulfate or iron concentrations of the sample were significant (indicating possible acid mine drainage contamination) or if the sampling site was located in an area known to have mine drainage problems.

Data actually recorded included name of water body, county, drainage basin, location of sampling site, dates, collectors, collector's code for the site, pH, conductivity, alkalinity, acidity, sulfate, whether or not fish were collected (or collection attempted), and if so, number of species found. This process generated a total of 983 cards representing different water bodies or locations within a stream system. Almost all these were streams, reflecting the small number of lakes within Pennsylvania and the little attention that has been given to their study. From these cards, all those were removed that did not meet the following criteria: there must be at least two samples (data points) and these must be separated in time by at least one year; either the pH or the alkalinity or both must show a decrease. Data from the remaining cards were used to generate the remaining tables and figures of this report.

P.C.F.R.U. - E.P.A. Study of Acid Precipitation Effects, 1979

Water Body _____ County _____ Card ___ of ___

Drainage _____ Sampling Site _____

Date

Collector

Coll's Code

pH

Conductivity

Alkalinity

Acidity

Sulfate

Fish Collection

(+ = present)
(0 = no try)
(- = absent)

NOTES

Figure 1. Card form used for recording and analysis of available data.

RESULTS AND DISCUSSION

A total of 983 cards were generated. Of these, 314 had two or more data points meeting the specified criteria, and were examined for trends. A decrease in pH, alkalinity, or both was found in 107 cases (40%). Seventy-one (66%) of these 107 records also had data from fish collections, and in 41 (58%) of these the number of species of fish present had decreased. A summary of the data on a statewide basis is presented in Table 1.

TABLE 1. SUMMARY OF DECREASES IN pH, ALKALINITY, AND NUMBER OF FISH SPECIES FOUND FOR PENNSYLVANIA AS A WHOLE.

Parameter	Mean of Earliest Data (Range)	Mean of Most Recent Data (Range)	Mean Net Change (Range)
pH (units)	7.31 (5.8--8.8)	6.94 (4.9--8.3)	-0.37 (-1.3 -- +0.2)
Alkalinity (ppm $CaCO_3$)	41.7 (5--200)	26.6 (2--186)	-15.1 (-105 -- +18)
Number of fish species	10.3 (2--22)	8.7 (1--21)	-1.53 (-15 -- +8)

Average time span between earliest and most recent data = 8.5 years (range 1--27).

The data extracted for the 107 stations showing decreases are presented in Table 2. Since it is difficult to detect overall trends in such a table, and because the effect is diluted by a number of increases in one parameter or another, we sought more meaningful methods of presentation.

Pennsylvania water chemistry is strongly influenced by topography, due to the very different types of rocks and soils exposed by different landforms. In many cases, the same stream undergoes a change of one or two hundred ppm in alkalinity, for example, within a few hundred yards as it leaves an inert sandstone mountainside and flows into a valley floor of highly reactive limestone. This sort of phenomenon may make it seem meaningless to sort stream data by major watersheds. We first chose to divide the state's counties into groups separated by lines denoting the major physiographic provinces, although in three cases it was necessary to divide a county between two provinces. A map indicating the location of "decrease" stations and these physiographic provinces is presented in Figure 2.

TABLE 2. pH, ALKALINITY, AND NUMBER OF FISH SPECIES FOR PENNSYLVANIA WATERS SHOWING DECREASES AS DESCRIBED IN TEXT. NA = data not available. Asterisk indicates that intermediate data exist which, if used, would indicate a decrease in the number of fish species.

Location Name	County	Earliest Data				Latest Data				Time Span	Net Change		
		Year	pH	Alka-linity	No. Fish Species	Year	pH	Alka-linity	No. Fish Species		pH	Alka-linity	No. Fish Species
Conewago Creek 1	Adams	69	7.3	37	20	77	7.1	36	18	8	-0.2	-1	-2
Conewago Creek 2	Adams	70	7.0	91	17	77	7.2	37	17	7	+0.2	-54	0
South Branch Conewago Creek	Adams	69	7.5	123	21	77	7.7	60	6	8	+0.2	-63	-15
Opossum Creek	Adams	70	7.5	60	17	77	7.2	40	17	7	-0.3	-20	0
Little Sewickly Creek	Allegheny	70	7.7	86	6	73	7.2	60	NA	3	-0.5	-@6	NA
Antietam Creek	Berks	69	7.7	122	16	76	7.3	62	11	7	-0.4	-60	-5
Northkill Creek	Berks	72	8.1	85	NA	74	7.6	70	NA	2	-0.5	-15	NA
Poplar Run	Blair	47	7.6	120	NA	67	7.0	15	7	20	-0.6	-105	NA
Sugar Creek	Bradford	69	8.7	85	14	78	7.8	62	NA	9	-0.9	-23	NA
South Branch Towanda Creek	Bradford	69	7.8	45	16	78	7.1	35	15	9	-0.7	-10	-1
Chest Creek 1	Cambria	67	7.6	45	10	70	7.2	41	NA	3	-0.4	-4	NA
Chest Creek 2	Cambria	67	7.7	79	15	69	7.1	22	NA	2	-0.6	-57	NA
North Creek	Cameron	47	7.7	21	NA	63	6.8	20	8	16	-0.9	-1	NA
Aquashicola Creek	Carbon	67	7.6	29	18	71	6.9	26	NA	4	-0.7	-3	NA
Sand Springs Run	Carbon	65	6.6	20	6	76	6.5	3	3	11	-0.1	-17	-3
Black Moshannon Creek	Centre	66	7.3	8	4	71	6.5	10	2	5	-0.8	+2	-2
Cherry Run	Centre	64	6.9	10	4	77	6.5	2	NA	13	-0.4	-8	NA
Cold Stream	Centre	66	7.0	15	6	72	6.2	NA	NA	6	-0.8	NA	NA
Elk Creek	Centre	65	8.3	120	8	76	8.3	108	7	11	0	-12	-1
Laurel (Whetstone) Run	Centre	61	7.1	11	11	78	6.9	10	5	17	-0.2	-1	-6
Little Fishing Creek	Centre	70	8.1	65	9	78	7.4	46	8	8	-0.7	-19	-1
Six Mile Run	Centre	76	7.2	NA	NA	78	6.5	NA	NA	2	-0.7	NA	NA
Pickering Creek	Chester	69	7.5	45	13	77	7.2	36	21	8	-0.3	-9	+8
Valley Creek	Chester	69	8.2	200	3	76	8.3	186	8	7	+0.1	-14	+5
Canoe Creek	Clarion	67	6.7	18	2	76	7.0	12	1	9	+0.3	-6	-1
Chest Creek	Clearfield	67	7.7	39	12	69	7.5	32	NA	2	-0.2	-7	NA
Gifford Run	Clearfield	72	6.3	NA	1	79	5.5	0	NA	7	-0.8	NA	NA
Little Clearfield Creek	Clearfield	66	7.3	40	11	71	7.1	38	NA	5	-0.2	-2	NA
Mosquito Creek	Clearfield	53	6.0	NA	NA	79	4.9	0	NA	26	-1.1	NA	NA
Panther Run	Clearfield	74	5.8	NA	NA	79	5.2	NA	NA	5	-0.6	NA	NA
West Branch Susquehanna River	Clearfield	67	7.3	17	2	74	6.9	2	NA	7	-0.4	-15	NA
Cooks Run	Clinton	61	6.9	NA	5	78	6.4	NA	NA	17	-0.5	NA	NA
Tangascootack Creek	Clinton	50	7.5	NA	NA	66	6.9	NA	5	16	-0.6	NA	NA
Beaver Run	Columbia	49	7.3	20	NA	76	7.0	14	14	27	-0.3	-6	NA
Armstrong Creek 1	Dauphin	69	7.2	13	14	76	6.8	9	11	7	-0.4	-4	-3
Armstrong Creek 2	Dauphin	69	7.0	7	16	76	6.7	6	14	7	-0.3	-1	-2
Stoney Creek 1	Dauphin	69	6.6	5	10	74	6.0	10	7	5	-0.6	+5	-3
Stoney Creek 2	Dauphin	64	6.9	5	13	74	6.4	10	5	10	-0.5	+5	-8
Belmouth Run	Elk	63	6.7	5	3	78	6.7	3	2	15	0	-2	-1
Youghiogheny River	Fayette	61	7.2	11	8	73	6.8	8	4	2	-0.4	-3	-4
East Standing Stone Creek	Huntingdon	61	7.3	12	7	76	6.9	5	10	15	-0.4	-7	+3
Globe Run	Huntingdon	61	6.9	6	11	76	6.3	8	8	15	-0.6	+2	-3
Trough Creek	Huntington	60	7.1	28	8	67	6.9	18	9	7	-0.2	-10	+1

(continued)

Table 2. (continued)

Location Name	County	Earliest Data				Latest Data				Time Span	Net Change		
		Year	pH	Alka-linity	No. Fish Species	Year	pH	Alka-linity	No. Fish Species		pH	Alka-linity	No. Fish Species
Five Mile Run	Jefferson	55	7.3	25	NA	72	7.0	12	4	17	-0.3	-13	NA*
Mill Creek	Jefferson	67	7.3	39	16	78	7.3	26	7	11	0	-13	-9
North Fork Redbank Creek	Jefferson	67	7.3	38	16	74	7.1	20	9	7	-0.6	-18	-7
Tuscarora Creek 1	Juniata	69	8.4	79	15	72	7.8	40	11	3	-0.6	-39	-4
Tuscarora Creek 2	Juniata	69	8.6	72	22	72	7.3	28	13	3	-1.3	-44	-9
Little Swatara Creek	Lebanon	57	7.6	81	NA	69	7.5	68	19	12	-0.1	-13	NA
Tulpehocken Creek	Lebanon	68	8.0	180	2	72	8.0	160	NA	4	0	-20	NA
Jordan Creek	Lehigh	69	8.0	93	14	72	7.5	40	NA	3	-0.5	-53	NA
Little Wapwallopen Creek	Luzerne	69	6.9	12	19	78	6.8	10	18	9	-0.1	-2	-1
Neslopeck Creek	Luzerne	66	6.7	8	NA	69	6.4	6	9	3	-0.3	-2	NA
North Branch Bowmans Creek	Luzerne	64	6.7	10	2	77	6.2	2	2	13	-0.5	-8	0
Little Bear Creek	Lycoming	64	6.8	10	3	74	6.8	4	4	10	0	-6	+1
Slate Run	Lycoming	64	7.4	30	7	78	7.2	15	8	14	-0.2	-15	+1
Trout Run	Lycoming	65	6.6	15	5	70	6.6	10	2	5	0	-5	-3
Kinzua Creek	McKean	63	6.9	20	15	67	6.9	12	NA	4	0	-8	NA
Jacks Creek	Mifflin	69	7.6	57	9	70	7.3	46	NA	1	-0.3	-11	NA*
Brodhead Creek	Monroe	69	8.1	22	12	78	7.3	18	8	9	-0.8	-4	-4
Cocolamus Creek	Perry	53	7.6	115	NA	69	7.8	40	18	16	+0.2	-75	NA
Fowler Hollow Run	Perry	64	6.5	10	5	77	6.0	2	6	13	-0.5	-8	+1
McCabes Run	Perry	64	7.5	35	15	75	6.9	10	6	11	-0.6	-25	-9
Sherman Creek 1	Perry	69	8.2	38	19	78	7.4	56	17	9	-0.8	+18	-2
Sherman Creek 2	Perry	64	6.5	15	10	77	6.4	4	13	13	-0.1	-11	+3
Little Bushkill Creek	Pike	65	7.6	20	13	78	6.3	7	8	13	-1.3	-13	-5
Middle Branch	Pike	65	7.3	30	10	76	6.2	3	8	11	-1.1	-27	-2
Saw Creek	Pike	65	6.8	NA	7	76	6.2	8	8	11	-0.6	NA	+1
Allegheny River 1	Potter	52	8.8	35	NA	70	7.5	12	18	18	-1.3	-23	NA
Allegheny River 2	Potter	52	6.9	33	NA	70	7.1	12	19	18	+0.2	-21	NA
Mill Creek	Potter	71	7.2	24	9	77	7.1	12	10	6	-0.1	-12	+1
Reed Run	Potter	62	7.2	28	14	76	7.1	12	9	14	-0.1	-16	-5
Swift Run	Snyder	64	6.5	10	3	77	6.3	2	3	13	-0.2	-8	0
Blue Hole Run	Somerset	65	6.7	20	3	77	6.5	4	2	12	-0.2	-16	-1
Clear Shade Creek	Somerset	65	7.1	15	9	76	6.3	5	5	11	-0.8	-10	-4
Fall Creek	Somerset	65	7.3	15	3	77	6.5	3	2	12	-0.8	-12	-1
Jones Mill Run	Somerset	65	7.3	25	5	77	7.0	15	5	12	-0.3	-10	0
Pole Branch Run	Sullivan	64	6.8	15	2	76	6.2	3	3	12	-0.6	-12	+1
Rock Run	Sullivan	54	6.9	9	NA	73	6.4	10	2	19	-0.5	+1	NA
East Branch Tunkhannock Creek	Susquehanna	69	7.5	40	13	77	7.0	20	13	8	-0.5	-20	0
North Branch Wyalusing	Susquehanna	69	7.4	23	18	78	6.8	18	11	9	-0.6	-5	-7
Salt Lick Creek	Susquehanna	69	7.5	30	10	78	7.2	24	17	9	-0.3	-6	+7
Cowanesque River	Tioga	69	7.7	58	12	77	7.4	32	13	8	-0.3	-26	+1
Four Mile Run	Tioga	64	7.3	40	2	73	7.3	23	4	9	0	-17	+2
Francis Branch Slate Run	Tioga	64	7.5	25	NA	71	7.0	23	5	7	-0.5	-2	NA
Long Run	Tioga	64	7.4	40	12	69	7.2	20	5	5	-0.2	-20	-7
Stoney Fork 1	Tioga	64	8.0	70	6	76	7.8	72	7	12	-0.2	+2	+1
Stoney Fork 2	Tioga	71	7.4	63	6	76	7.4	52	6	5	0	-11	0

(continued)

Table 2. (continued)

Location Name	County	Earliest Data				Latest Data				Time Span	Net Change		
		Year	pH	Alka-linity	No. Fish Species	Year	pH	Alka-linity	No. Fish Species		pH	Alka-linity	No. Fish Species
Straight Run	Tioga	64	7.4	35	6	76	7.1	22	5	12	-0.3	-13	-1
Tioga River 1	Tioga	73	7.3	8	7	78	6.4	6	8	5	-0.9	-2	+1
Tioga River 2	Tioga	71	6.4	10	NA	78	5.3	3	NA	7	-1.1	-7	NA
Laurel Run	Union	64	6.8	15	8	77	6.7	7	9	13	-0.1	-8	+1
Weikert Run	Union	64	6.8	15	9	77	6.5	5	4	13	-0.3	-10	-5
Little Sandy Creek	Venango	65	7.7	100	12	77	7.8	42	5	12	+0.1	-58	-7
Four Mile Run	Warren	54	7.3	73	NA	75	7.1	24	6	21	-0.2	-49	NA
Dyberry Creek	Wayne	69	7.2	30	16	77	7.1	20	13	8	-0.1	-10	-3
Lackawaxen Creek	Wayne	69	7.6	30	11	78	7.1	17	17	9	-0.5	-13	+6
Shadigee Creek	Wayne	69	7.3	35	11	76	7.2	28	13	7	-0.1	-7	+2
Wallenpaupack Creek	Wayne	69	7.2	17	13	78	6.7	12	15	9	-0.5	-5	+2
West Branch Dyberry Creek	Wayne	65	8.2	30	11	77	7.1	22	10	12	-1.1	-8	-1
Four Mile Run	Westmoreland	67	7.3	38	19	77	7.4	21	20	10	+0.1	-17	+1
Bowmans Creek	Wyoming	64	6.8	15	10	77	6.8	2	7	13	0	-13	-3
North Branch Mehoopany Creek	Wyoming	69	7.9	32	8	77	7.2	24	8	8	-0.7	-8	0
Tunkhannock Creek 1	Wyoming	66	8.0	32	NA	69	7.4	44	12	3	-0.6	+8	NA
Tunkhannock Creek 2	Wyoming	66	8.0	30	NA	69	7.6	33	18	3	-0.4	+3	NA
Toms Run	York	70	7.1	14	6	77	6.9	11	10	7	-0.2	-3	+4
West Branch Codorus Creek	York	70	7.3	137	7	78	7.5	98	5	8	+0.2	-39	-2

NA = Data not available.
* = Intermediate data indicate a decrease in number of species.

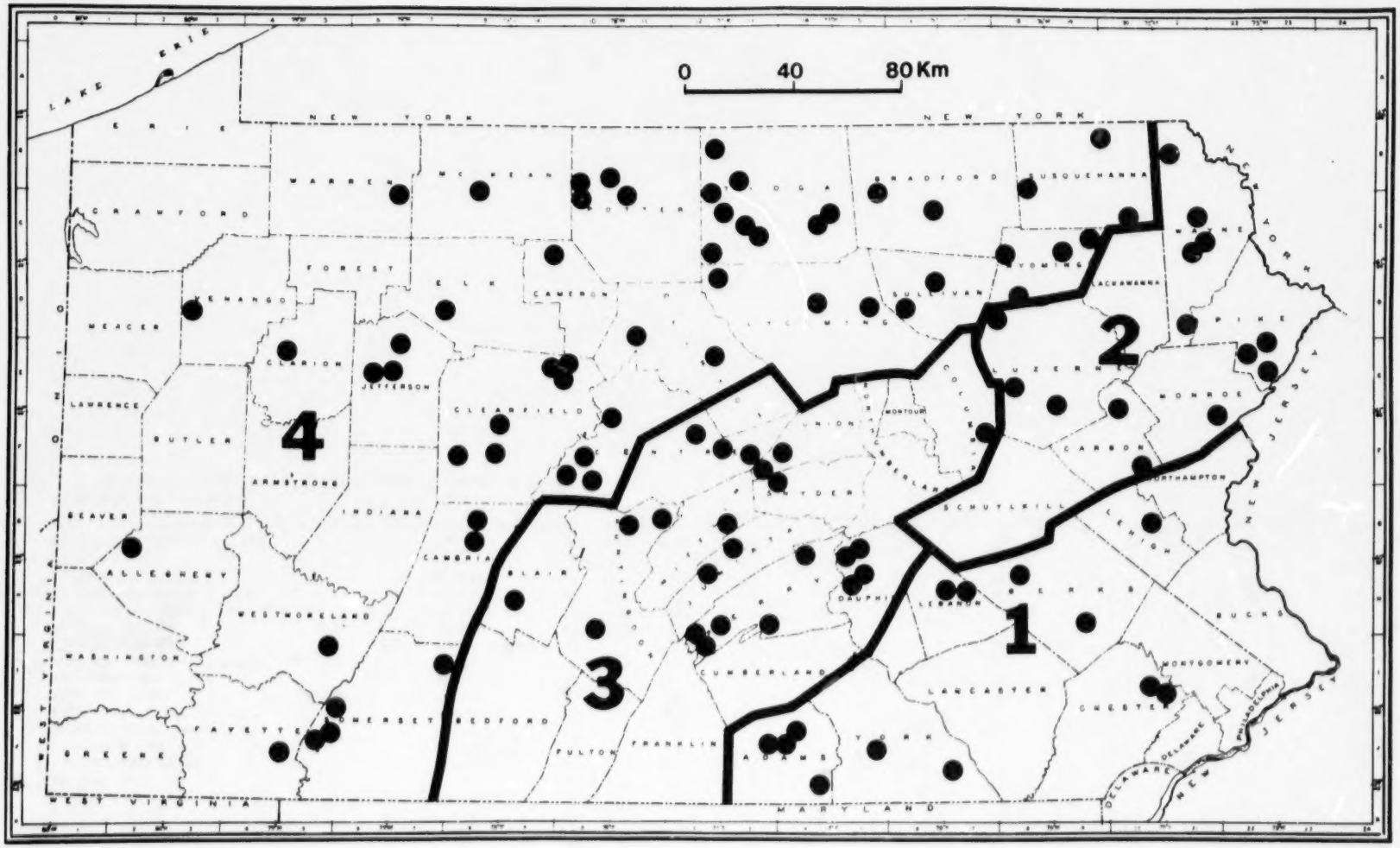

Figure 2. County map of Pennsylvania showing approximate boundaries of physiographic provinces and locations of waters showing decrease in pH or alkalinity or both. Key to numbers: 1) Coastal-Piedmont province; 2) Pocono-Anthracite province; 3) Ridge and Valley province; 4) Allegheny Plateau province (see Table 3). Scale 1:2,500,000.

The four provinces which we have delineated follow both topographic and geologic features, and for our purposes may be described as follows:

1. Coastal—Piedmont. Flat to rolling hills, Cambrian limestone and dolomite, some areas of Triassic shales and sandstones and Ordovician/Precambrian metamorphic rocks.

2. Pocono-Anthracite. High rolling mountains mostly of Devonian shale and sandstone; occasional limestone exposures in association with coal seams.

3. Ridge and Valley. Long, high, parallel ridges of Devonian sandstones giving rise to infertile waters locally called "freestone streams." Valley floors of Ordovician and Cambrian limestones, dolomites, and shales with streams becoming relatively fertile and alkaline as they flow off the ridges into the valleys.

4. Allegheny Plateau. High, rolling mountains in irregular patterns. Cyclic sequences of Pennsylvania sandstones, limestones, shales, clays, and coals; but most higher elevations, especially in northern part, overlain by sandstone and shale beds of low solubility.

The approximate boundaries of our four physiographic provinces are shown in Figure 2, along with the locations of streams showing decreases in pH, alkalinity, or both. A summary of the relevant data is presented in Table 3. Divided in this way, the available data still show no striking irregularity. Total number of streams identified is closely related to the size of the province, and the proportion showing decreases in pH, alkalinity, and/or fish species number is relatively constant. However, this in itself may be important, indicating that either the distribution of susceptible streams, or of acid precipitation, or both, are statewide. Resolution of this point will require statistical analysis for which neither time nor funds were available at this writing. We expect to perform this analysis and publish the results in the near future.

Although earlier questioned, the obvious alternative method of examining the data is by major watershed. The major watersheds of Pennsylvania, along with the locations of the "decrease" streams, are shown in Figure 3. A summary of the data sorted by watershed is presented in Table 4. This arrangement of the data does reveal some interesting trends, although their real meaning is not at all certain. For example, the proportion of the identified streams showing decreases in pH or alkalinity is quite low in the Allegheny River drainage, but the proportion of "decrease" streams showing a decrease in fish species number is quite high. The latter proportion is also quite high in the Delaware and Susquehanna below Sunbury (main stem) drainages as well as in the Monongahela-Youghiogheny system, although the data for the latter are very limited. Since the latter three drainages are not areas which we suspected of being very susceptible to acid precipitation, we are reluctant to speculate on the meaning of these trends in the data.

Nevertheless, it seems clear that there is a definite overall trend of many streams becoming more acidic and/or less alkaline, and losing some fish populations at the same time. We hope that we or some other agency will be

TABLE 3. WATER CHEMISTRY AND FISH POPULATION RECORDS SUMMARIZED BY PHYSIOGRAPHIC PROVINCE.

Province	Total Number* of Streams Examined (Percent of Grand Total)	Number Decreasing in pH, Alkalinity, or Both	Number with Fish Data	Number with Decrease in Fish Species
1. Coastal-Piedmont	55 (18%)	13 (24%)	9	4 (44%)
2. Pocono-Anthracite	45 (14%)	14 (31%)	12	7 (58%)
3. Ridge and Valley	62 (20%)	23 (37%)	18	12 (67%)
4. Allegheny Plateau	152 (48%)	57 (37%)	32	18 (56%)
Totals	314	107	71	41

* Having two or more data points and no evidence of mine drainage.

TABLE 4. WATER CHEMISTRY AND FISH POPULATION RECORDS SUMMARIZED BY MAJOR WATERSHED.

Watershed (Numbers as in Figure 3)	Total Number* Locations Examined	Number Decreasing in pH, Alkalinity, or Both	Number with Fish Data	Number with Decrease in Fish Species
1. Lake Erie	7	0	0	0
2. Ohio below Pittsburgh	3	1 (33%)	0	0
3. Monongahela-Youghiogheny	9	4 (44%)	4	3 (75%)
4. Allegheny	48	14 (29%)	9	7 (78%)
5. West Branch Susquehanna	66	29 (44%)	13	6 (46%)
6. Susquehanna below Sunbury	79	28 (35%)	23	14 (61%)
7. Potomac	3	0	0	0
8. North Branch Susquehanna	44	15 (34%)	10	4 (40%)
9. Delaware	55	16 (29%)	12	7 (58%)
Totals	314	107 (34%)	71	41 (58%)

* Having two or more data points and no evidence of mine drainage.

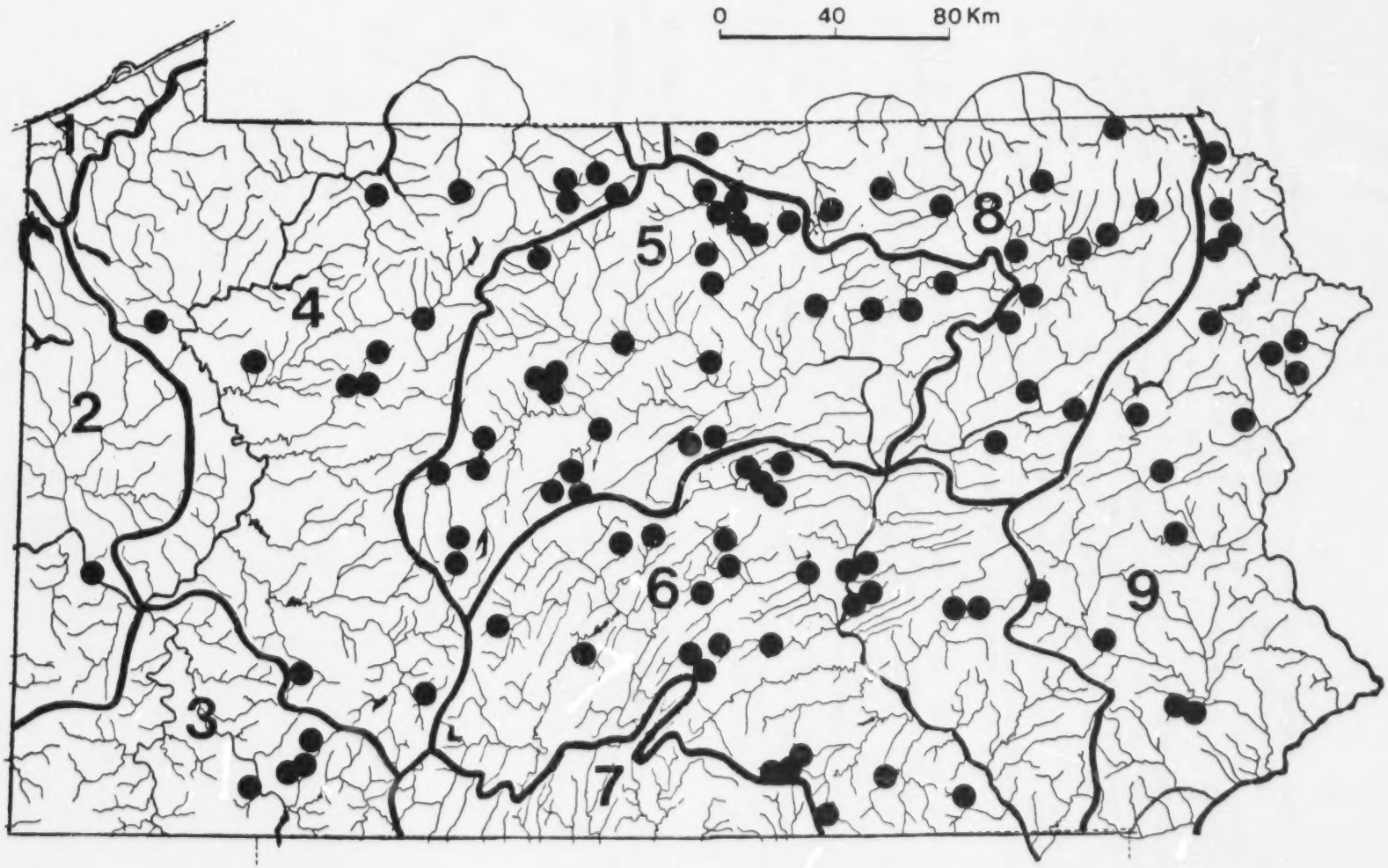

Figure 3. Stream map of Pennsylvania showing major drainage basins and locations of waters showing decrease in pH or alkalinity or both. Key to numbers: 1) Lake Erie; 2) Ohio below Pittsburgh; 3) Monongahela-Youghiogheny; 4) Allegheny; 5) West Branch Susquehanna; 6) Susquehanna below Sunbury; 7) Potomac; 8) North Branch Susquehanna; 9) Delaware (see Table 4). Scale 1:2,500,000.

able to institute a program of investigation which will supplement the available data with information needed to document the current condition and trend of many of these streams. We would be the first to admit that measurements of pH and alkalinity on a single stream during one day or one year can be highly variable; that it is very likely many of the data we used were generated in different ways and with different degrees of accuracy; and that the two measurements available in many of our cases are hardly enough to establish a statistically valid trend. However, we feel that the weight of the evidence becomes strong when so many of these cases, however imperfect, point in the same direction. Many chances for mitigation of ecological "disasters" have been lost because no one was willing to make a commitment until statistically unquestionable proof was not only in hand but widely accepted. We hope that will not be the case with the acid precipitation problem.

As a start in what we hope is the right direction, we have been experimenting with static limestone beds and other devices to mitigate the problems caused by acidification of Pennsylvania's fragile mountain trout streams. In the process of this work we have documented water quality in a number of streams which approaches the lower lethal limit of pH for brook trout, one of the most hardy of the native species. Since our study has been centered in the Quehanna Wilderness Area of Clearfield County, most of these streams are located there, but we can not believe that there are not others equally fragile and/or degraded in other areas. Naturally air quality control will be their best hope.

In Table 5 we present a list of streams identified either in our earlier work or from the present study which illustrates the probable worst conditions existing at present in Pennsylvania streams and lakes which are not affected by acid mine drainage. We suggest that these streams should be watched closely to document whatever changes in their ecosystems have or will occur.

TABLE 5. SELECTED WATERS SHOWING SERIOUS SYMPTOMS OF ACIDIFICATION (data from 1978-1979; N = number of samples).

Name	County	Mean pH (N) (range)	Mean Alkalinity (N) (range)
Gifford Run	Clearfield	5.26 (26) (4.6-5.9)	1.5 (12) (0-9.1)
Mosquito Creek	Clearfield and Elk	5.22 (13) (4.7-5.9)	0.6 (5) 0-2.85)
Deer Creek	Clearfield	5.23 (10) (4.8-5.5)	0 (5) (0-0)
Pebble Run	Elk	(4.66 (15) (4.4-5.0)	0 (5) (0-0)
Panther Run	Clearfield	5.26 (15) (4.9-5.7)	0 (8) (0-0)
Tioga River	Tioga	6.85 (2) (6.4-7.3)	7 (2) (6-8)
*Tuscarora Creek	Juniata	8.03 (3) (7.3-8.6)	61(3) (28-83)
*Allegheny River	Potter	8.15 (2) (7.5-8.8)	48.5 (2) (12-85)
*West Branch Dyberry Creek	Wayne	7.65 (2) (8.2-7.1)	76.5 (2) (66-87)
Lower Duck Pond (Tributary of Mosquito Creek)	Clearfield	5.26 (7) (4.9-5.4)	0 (3) (0-0)
Sandy Creek	Clearfield	5.33 (11) (4.7-5.6)	0.15 (12) (0-1.81)
Meeker Run	Clearfield and Cameron	4.8 (1) (4.8)	4.05 (1) (4.05)

* These streams, while not exhibiting abnormally low pH or alkalinity, did exhibit significant changes in these or in fish populations over the time period examined, and thus will bear watching.

REFERENCES

Almer, B., W. Dickson, C. Eckstrom, E. Hornstrom, and U. Miller. 1974. Effects of acidification on Swedish lakes. Ambio 3(1):30-36.

Beamish, R. J., and H. H. Harvey. 1972. Acidification of the LaCloche Mountain lakes, Ontario, and resulting fish mortalities. J. Fish. Res. Bd. Canada 29(8):1131-1143.

Bender, P. M. 1978. Studies on the periphyton communities of two infertile mountain streams with differing pH. M.S. Thesis, The Pennsylvania State University, University Park, 42 pp.

Brosset, C. 1973. Air-borne acid. Ambio 2(1):2-9.

Carter, L. J. 1979. Uncontrolled SO_2 emissions bring acid rain. Science 204(4398):1179, 1181-1182.

Cooper, E. L. and C. C. Wagner. 1973. The effects of acid mine drainage on fish populations. Pages 73-124 In R. L. Butler, E. L. Cooper, J. K. Crawford, D. C. Hales, W. G. Kimmel and C. C. Wagner, Fish and food organisms in acid mind waters of Pennsylvania. U.S. Env. Prot. Agency. Ecol. Res. Ser., Rep. No. EPA-R3-73-032. U.S. Government Printing Office, Washington, D.C. 158 pp.

Hale, A. B. 1978. A comparative study of the insect communities in two woodland streams with differing pH, with notes on the growth and fecundity of two species of Leuctra (Plecoptera). M.S. Thesis, The Pennsylvania State University, University Park. 50 pp.

Johnson, N. M., R. C. Reynolds and G. E. Likens. 1972. Atmospheric sulfur: its effect on the chemical weathering of New England. Science 177(4148): 514-516.

Kellogg, W. W., R. D. Cadle, E. R. Allen, A. L. Lazrus and E. A. Martell. 1972. The sulfur cycle. Science 175(4022):587-596.

Likens, G. E. and F. H. Bormann. 1974. Acid rain: a serious regional environmental problem. Science 184(4142):1176-1179.

Likens, G. E., R. F. Wright, J. N. Galloway and T. J. Butler. 1979. Acid rain. Sci. Amer. 241(4):43-51.

Newman, L. 1975. Acidity in rainwater: has an explanation been presented? Science 958(4191):957-958.

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Schofield, C. L. 1976. Acid precipitation: effects on fish. Ambio 5(5-6): 228-230.

Schofield, C. L. 1977. Acid precipitation's destructive effects on fish in the Adirondacks. New York's Food Life Sci. 10(3):12-15.

Seip, H. M. and A. Tollan. 1978. Acid precipitation and other possible sources for acidification of rivers and lakes. Sci. Total. Env. 10(3): 253-270.

Vermeulen, A. J. 1978. Acid precipitation in The Netherlands. Env. Sci. Tech. 12(9):1016-1021.

Wright, R. F. 1976. Acid precipitation and its effects on freshwater ecosystems: an annotated bibliography. Proc. 1st Int. Symp. Acid Precip. For. Ecos., U.S.D.A. Forest Serv. Gen Tech. Rep. NE-23:619-678.